Energy and Buildings 108 (2015) 215–222

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Experimental study on a novel fuzzy control method for static pressure reset based on the maximum damper position feedback

Jili Zhang*, Xiuming Li, Tianyi Zhao, Wuhe Dai

Faculty of Infrastructure Engineering, Dalian University of Technology, Dalian 116024, China

ARTICLE INFO

Article history:
Received 11 March 2015
Received in revised form 12 August 2015
Accepted 9 September 2015
Available online 10 September 2015

Keywords:
Static pressure reset
Fuzzy control
Damper position feedback

ABSTRACT

In variable air volume (VAV) systems, conventional control methods reset the supply air static pressure based on the exact mathematics model of the controlled objects which are often difficult to be founded, because the VAV controlled systems have the characteristics of nonlinear, multivariable and long delay times. In order to develop a simple inference process for real-time applications, this paper presents a novel fuzzy control method for static pressure reset with no using of the mathematics model. The proposed fuzzy control method is developed based on the maximum damper position feedback using Mamdani-type fuzzy rule and functioning fuzzy subset inference (FFSI). This study provides the detail implement process of the proposed fuzzy control method. Supported by the experimental data, the proposed method is compared with optimal fixed changing step method in an integrated control test rig for a VAV air conditioning system. Experimental results show that the proposed method has better energy efficient and control performance. A minimum of 7% energy saving of the proposed fuzzy control method is shown through experimental study.

1. Introduction

A variable air volume (VAV) system allows the supply fan speed regulated by variable frequency drive (VFD) to save energy. The most common control method is to regulate supply fan speed so as to maintain the measured static pressure at its set-point. The supply air static pressure shall meet the requirement of providing enough static pressure to all the VAV terminals, so that the damper positions of corresponding VAV terminals could be modulated according to their load demands. However, an excessive static pressure level often exists due to the conservative estimate. Therefore, the supply air static pressure in VAV systems should be kept as low as possible to save supply fan energy. In other words, there is high potential to save supply fan energy consumption by optimizing supply air static pressure.

1.1. Literature review

Researches and practices have been focused on the development and the implement of static pressure reset control strategy in order to reduce supply fan energy consumption [1,2]. Liu introduced a reset strategy based on total supply airflow ratio, which is measured by a fan airflow station [3]. Liu also presented a simplified in-situ fan curve measurement procedure using the manufacturers fan curve in order to improve the airflow rate measurement accuracy [4]. Shim compared three different strategies for resetting supply air static pressure through simulations and experiments. The results show the strategy which utilizes total air flow can save significant energy [5].

The damper position of the VAV terminal directly effects the system resistance which could be reduced by controlling the damper position of the VAV terminal to open widely, as a result, the supply fan energy consumption will be reduced when the damper position of the VAV terminal is kept the largest opening degree as far as possible. The conventional methods based on the VAV damper position to control the supply fan are widely implemented [6,7]. Wei and Liu presents an integrated damper and pressure reset method for VAV air condition system fan control, which controls the supply air static pressure at a minimum required level [8]. Taylor proposes Trim & Respond control logic, which is more effective than PID logic at reducing fan energy consumption, under the condition of the highly interactive relationship between static pressure set-point and the damper position feedback of the VAV terminal [9].

Some researchers aim to develop intelligent control methods. Ning developed a supervisory optimal control strategy based on an artificial neural network to find several optimal set points including the supply air static pressure. Significant energy (10% under full load condition, 19% under partial load condition) was saved

* Corresponding author. Tel.: +86 041187407753.
E-mail address: lixiuming@mail.dlut.edu.cn (J. Zhang).

http://dx.doi.org/10.1016/j.enbuild.2015.09.014
0378-7788/

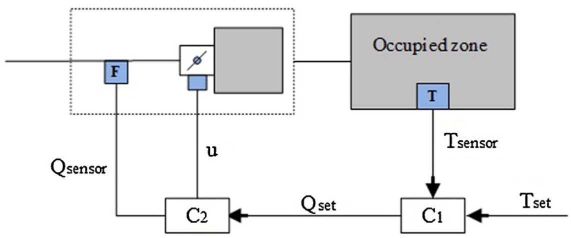

Fig. 1. Control scheme of the pressure-independent VAV terminal.

according to the simulation results [10]. Wang provided a practically applicable fault tolerant control strategy for pressure-independent VAV systems. Different from the conventional strategy, the developed strategy did not require the damper position of the VAV terminal [11].

1.2. Critique

The airflow based control methods have to depend on the accurate airflow rate measurement, however, inaccurate airflow rate measurement is always there due to measuring error and sensor fault [12–15]. The damper position feedback based control methods have improved the control performance of static pressure reset based on the damper position feedback of the VAV terminal well. However, it is difficult to set up an exact mathematics model between static pressure set-point and the damper position feedback of the VAV terminal, because the VAV controlled systems have the characteristics of nonlinear, multivariable and long delay times. Therefore, the change direction of static pressure reset could be obtained directly, but the variable quantity could not be obtained accurately. This will increase the commissioning difficulty and reduce the operational stability.

1.3. Research problem

In order to develop a simple inference process for real-time applications, a novel fuzzy control method for static pressure reset is presented using Mamdani-type fuzzy rule and functioning fuzzy subset inference (FFSI). This paper firstly introduces the deterministic process of the reference variable for pressure-independent VAV terminals, and the maximum damper position feedback is considered as the reference variable. By theoretical analysis and experimental study, the proposed fuzzy control method is compared with optimal fixed changing step method in an integrated control test rig for a VAV air conditioning system.

This paper is organized as follows: Section 2 describes the proposed control method for pressure-independent VAV systems. Section 3 demonstrates the fuzzy control theory with functioning fuzzy subset inference (FFSI). Section 4 demonstrates the experimental study and the implementation process of the proposed fuzzy control method, including (a) system description, (b) the implementation process of the proposed fuzzy control method, (c) optimal fixed changing step method for comparison, and (d) results and discussions. The final section presents the conclusions.

2. Proposed control method

2.1. The pressure independent VAV terminals

The typical VAV terminal to be controlled is illustrated in Fig. 1, where the zone temperature T_{sensor} follows its set-point T_{set} by adjusting the supply airflow Q_{set} according to the indoor load [16]. The supply airflow is controlled by the terminal damper position feedback inside the VAV terminal. Two cascaded controllers, i.e. C1 and C2 in Fig. 1, are used to realize a pressure independent control [17]. The controller C1 takes T_{sensor} and T_{set} as the inputs and Q_{set} as the output. The controller C2 takes Q_{set} and Q_{sensor} (the measurement of airflow) as the input signal and u as the output. The output u is the control signal for the damper position. The pressure independent control divides the single zone VAV thermal system into a zone temperature process and a VAV damper process. The zone temperature process produces set-points for the airflow according to occupancies' thermal requirement and the indoor load, while the VAV damper process tracks the set-point by adjusting the damper position of the VAV terminal.

2.2. The reference variable for static pressure reset

If the damper position of a certain VAV terminal is the maximum damper position among all the VAV terminals at a period of time, the damper position feedback of this VAV terminal is defined as the maximum damper position feedback. It is noteworthy that the maximum damper position feedback may not be 100% open and is just relative to others. In this paper, the maximum damper position feedback is considered as the reference variable.

In addition, if several maximum damper position feedbacks exist at the same time, the maximum airflow rate deviation between measured value and setting value is considered as the reference variable. The airflow setting value Q_{set}, which is described as Eq. (1), represents the indoor load demand [4].

$$Q_{set} = \frac{Q_{designMAX} - Q_{designMIN}}{100} \times Y + Q_{designMIN} \quad (1)$$

where $Q_{designMAX}$ is the maximum airflow design value; $Q_{designMIN}$ is the minimum airflow design value; Y is the direct output signal of PID controller C1.

3. Fuzzy control theory

3.1. Literature review

It is very difficult to obtain satisfactory control results for the complex controlled systems, which have the characteristics of nonlinear, multivariable and have long delay times, by the traditional control methods, because the traditional control methods demand accurate mathematical models of the controlled objects which are often difficult to be founded. On the contrary, fuzzy control can perform very good effects based only on the control rules developed by experts and operators from their experience. Since Zadeh put forward fuzzy sets in 1965, fuzzy control has been widely used in the control process of the HVAC systems [18–20].

There are two main fuzzy models including the Mamdani style and the Takagi–Sugeno style, and the former is frequently used in the fuzzy control [18]. On the basis of this principle and the real-time control demand of HVAC systems, the FFSI has been put forward, the single-chip fuzzy controller based on the FFSI has been developed [21,22]. By means of Mamdani-type fuzzy rules and the FFSI, Zhao presents a duty ratio fuzzy control method according to the deviation and deviation changes of the room temperature [23]. Chen presents a self-organizing rules fuzzy control controller with the FFSI in order to carry out fuzzy control experiments in the supply air system [24].

3.2. Critique

It is unquestionable that fuzzy control either in stand-alone applications or in combination with other intelligent methods contributes in the minimization of energy consumption. However, conventional control methods still dominate the researchers' interests. The main disadvantage of the application of fuzzy control is the